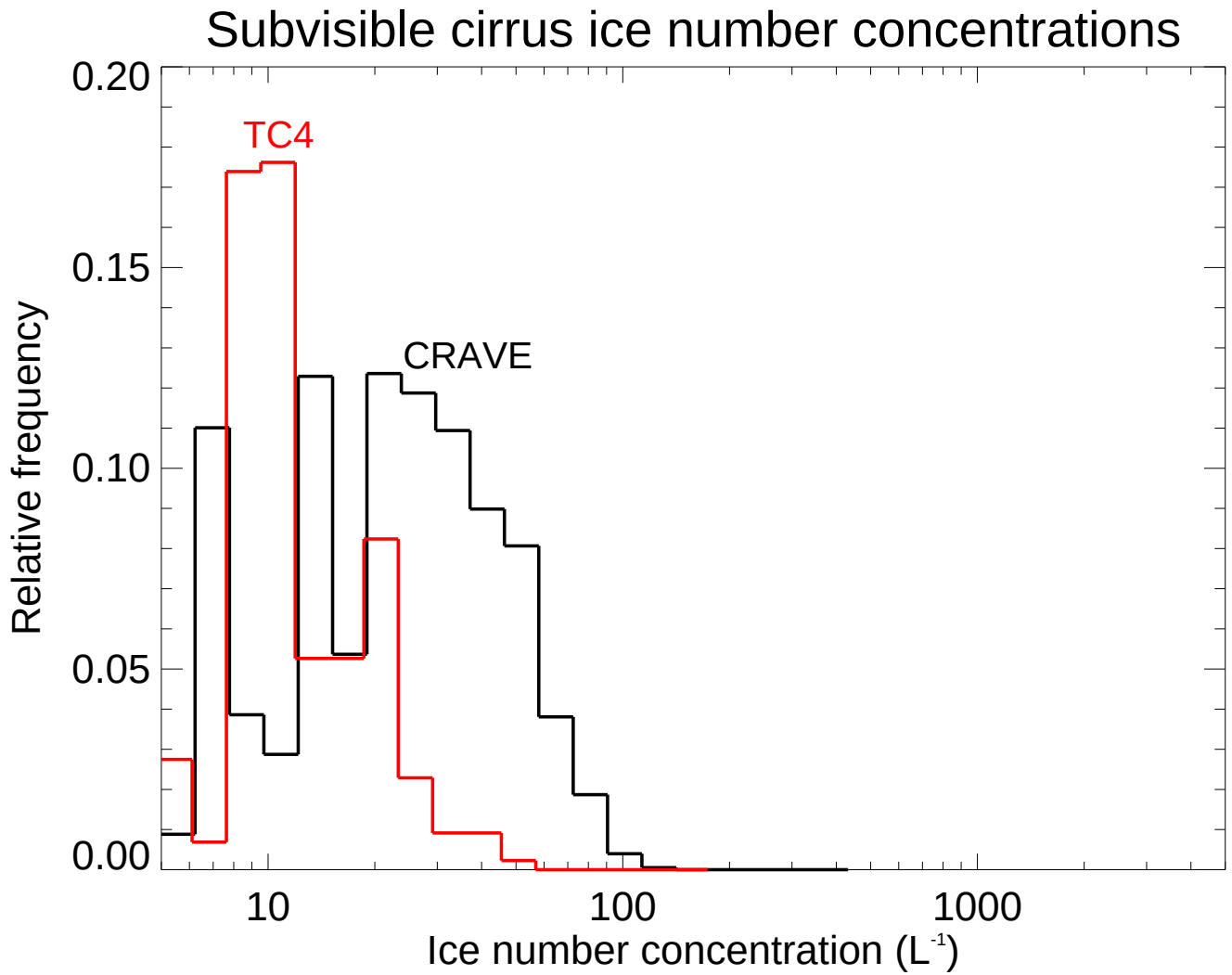
Ice Nucleation at Low TTL Temperatures

SVC →

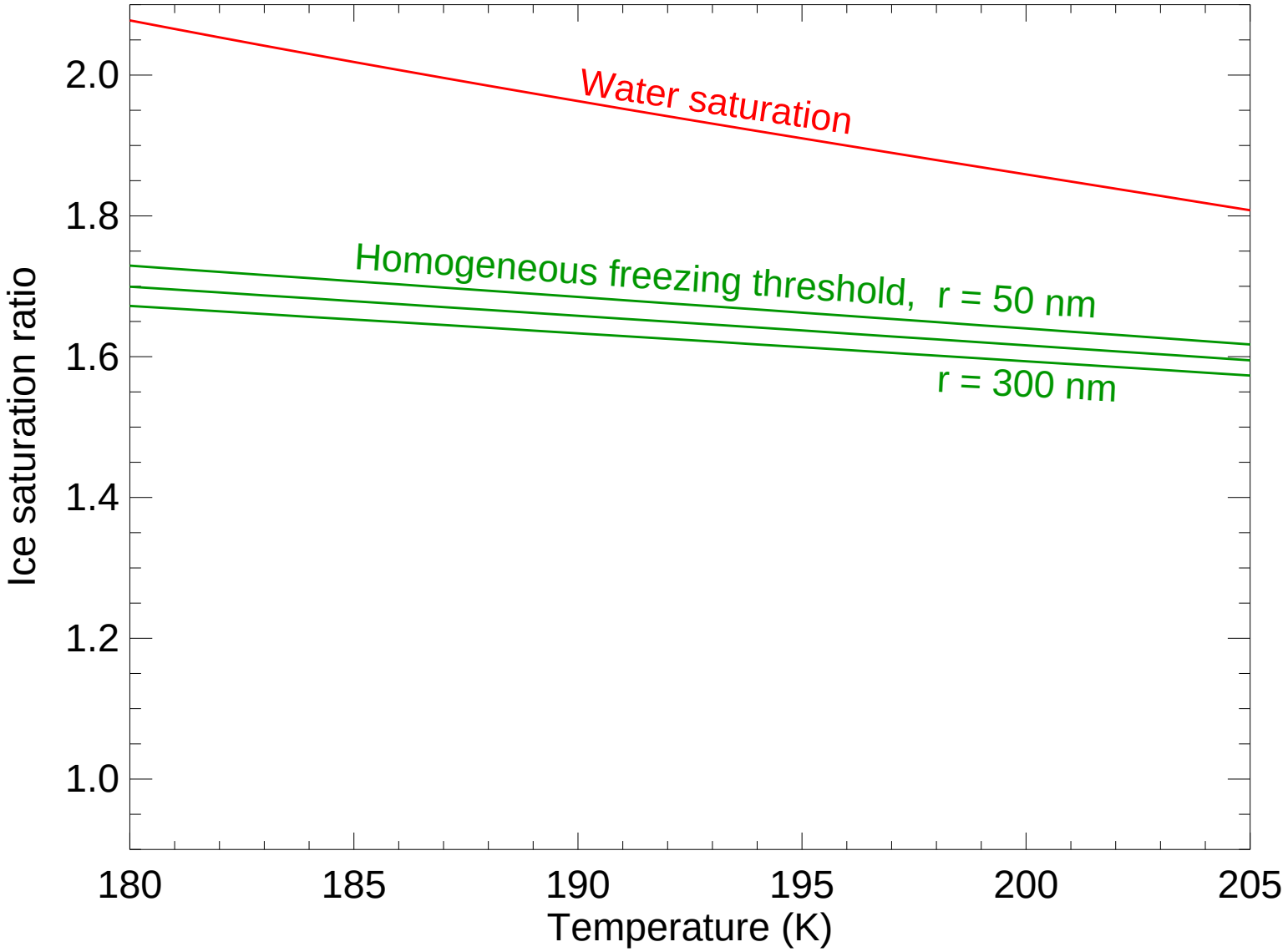
- Understanding ice nucleation in TTL cirrus is important:
  - Evaluating impact of anthropogenic aerosols
  - Supersaturation required for ice nucleation affects dehydration potential
  - Cloud lifetime depends on ice crystal size distribution
- Our understanding of nucleation processes at low T is limited.



- Consistently low ice concentrations measured in TTL cirrus from multiple campaigns (PreAVE, CRAVE, TC4, AMMA, SCOUT, etc.)

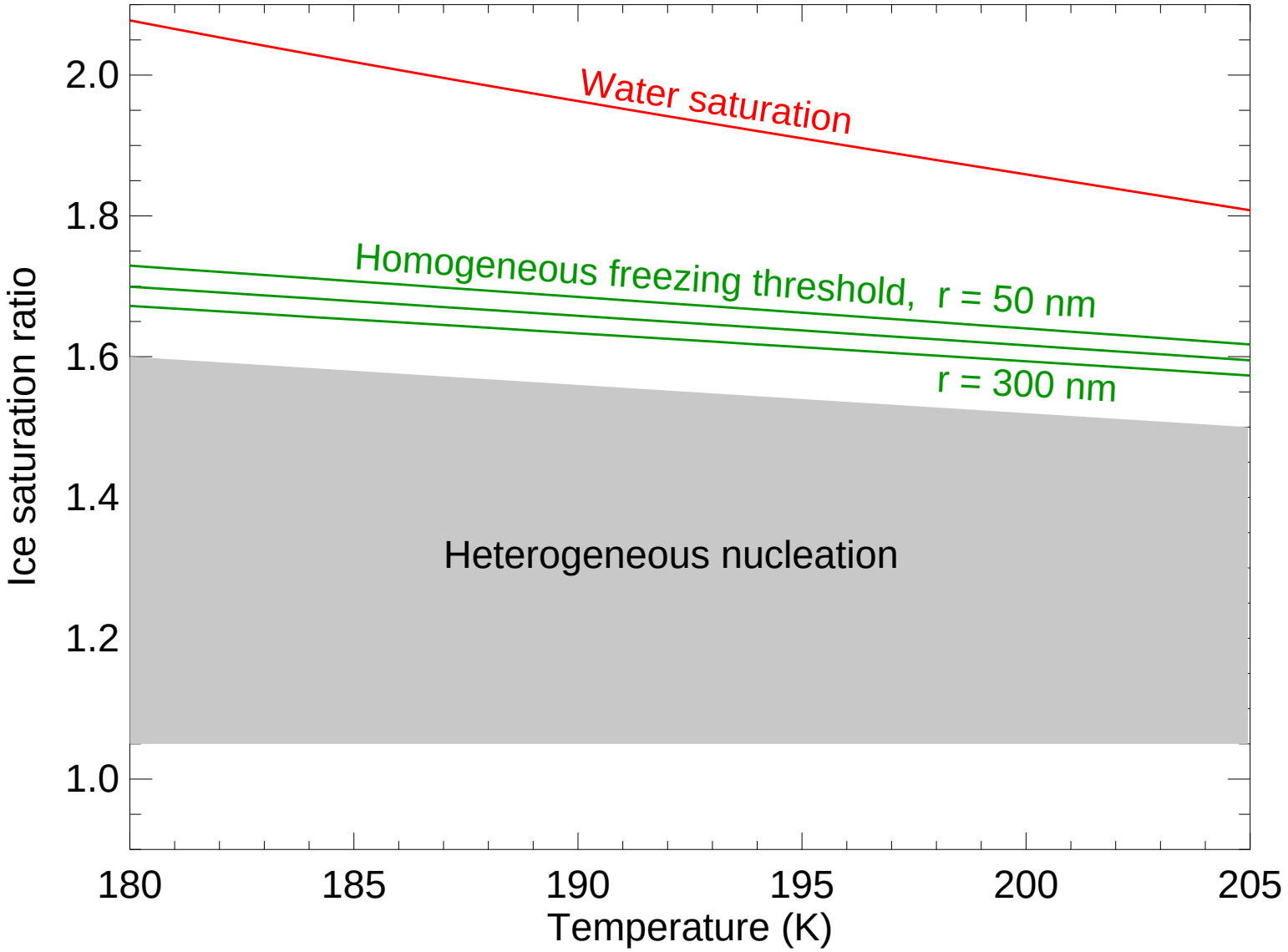
- Lawson et al. [ACP,2008], Krämer et al. [ACPD,2008]

Ice nucleation at low Temperatures



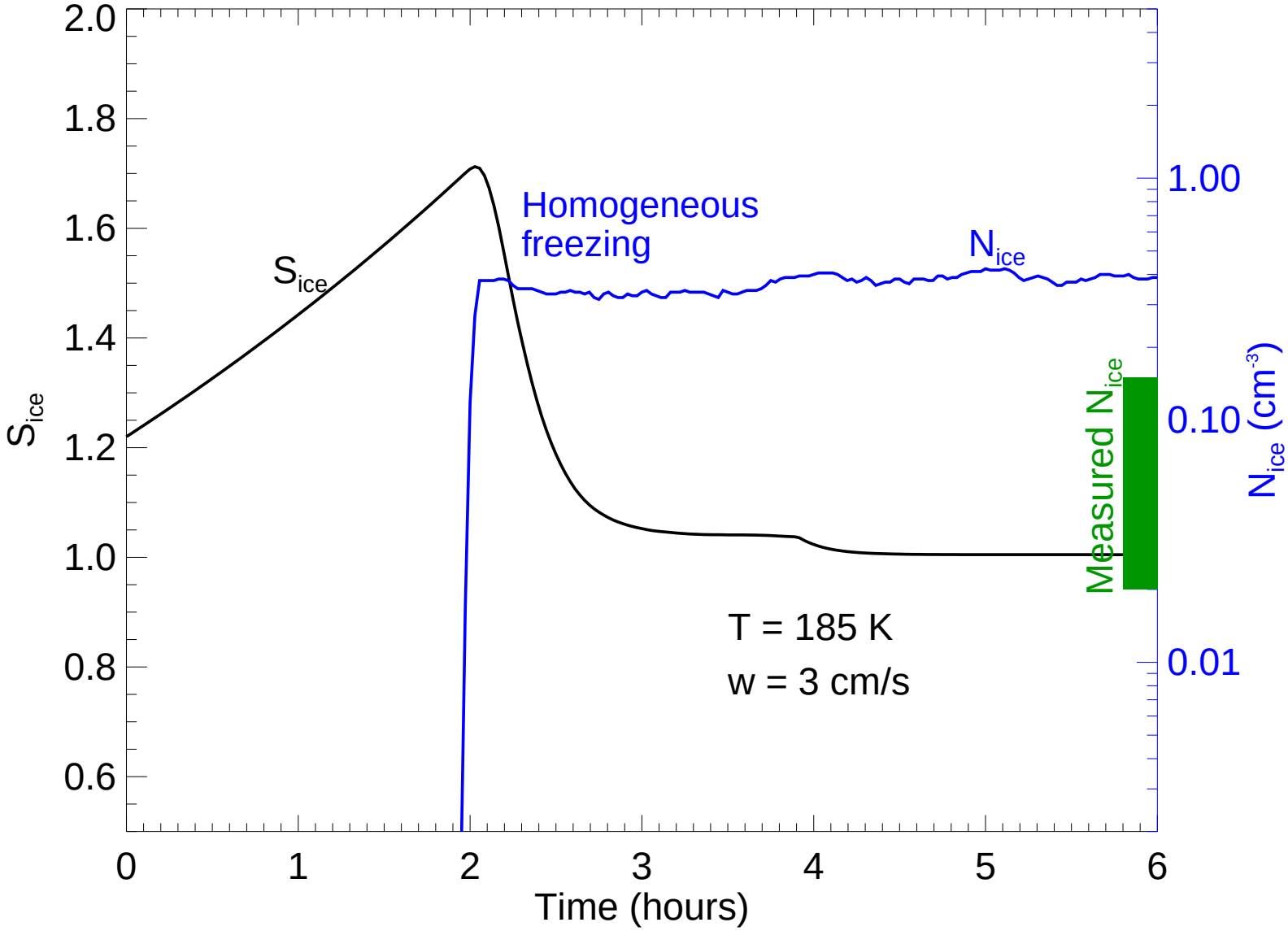
- Homogeneous freezing requires large supersaturations

Ice nucleation at low Temperatures



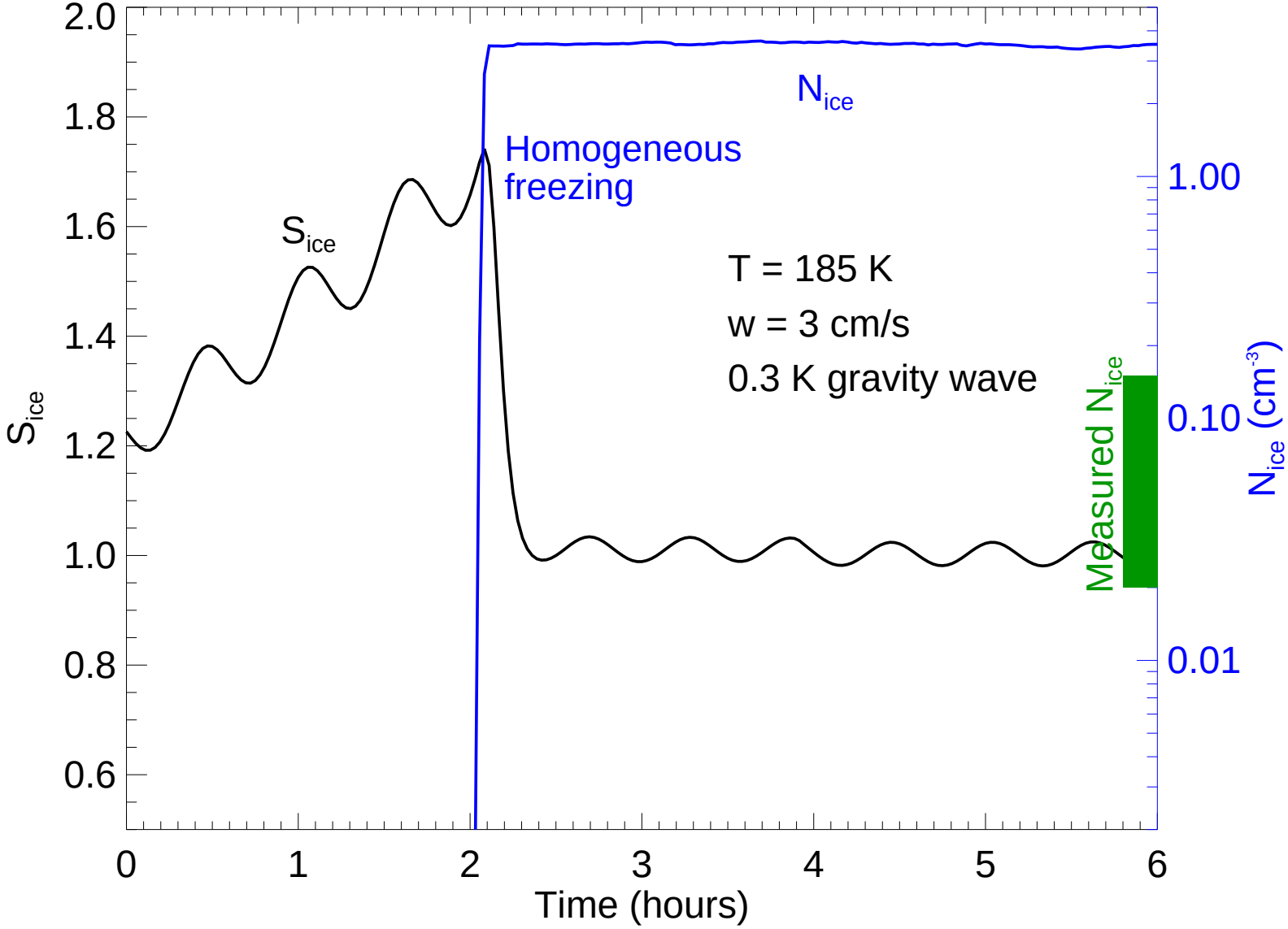
- Heterogeneous freezing can occur at low supersaturations

Homogeneous freezing event



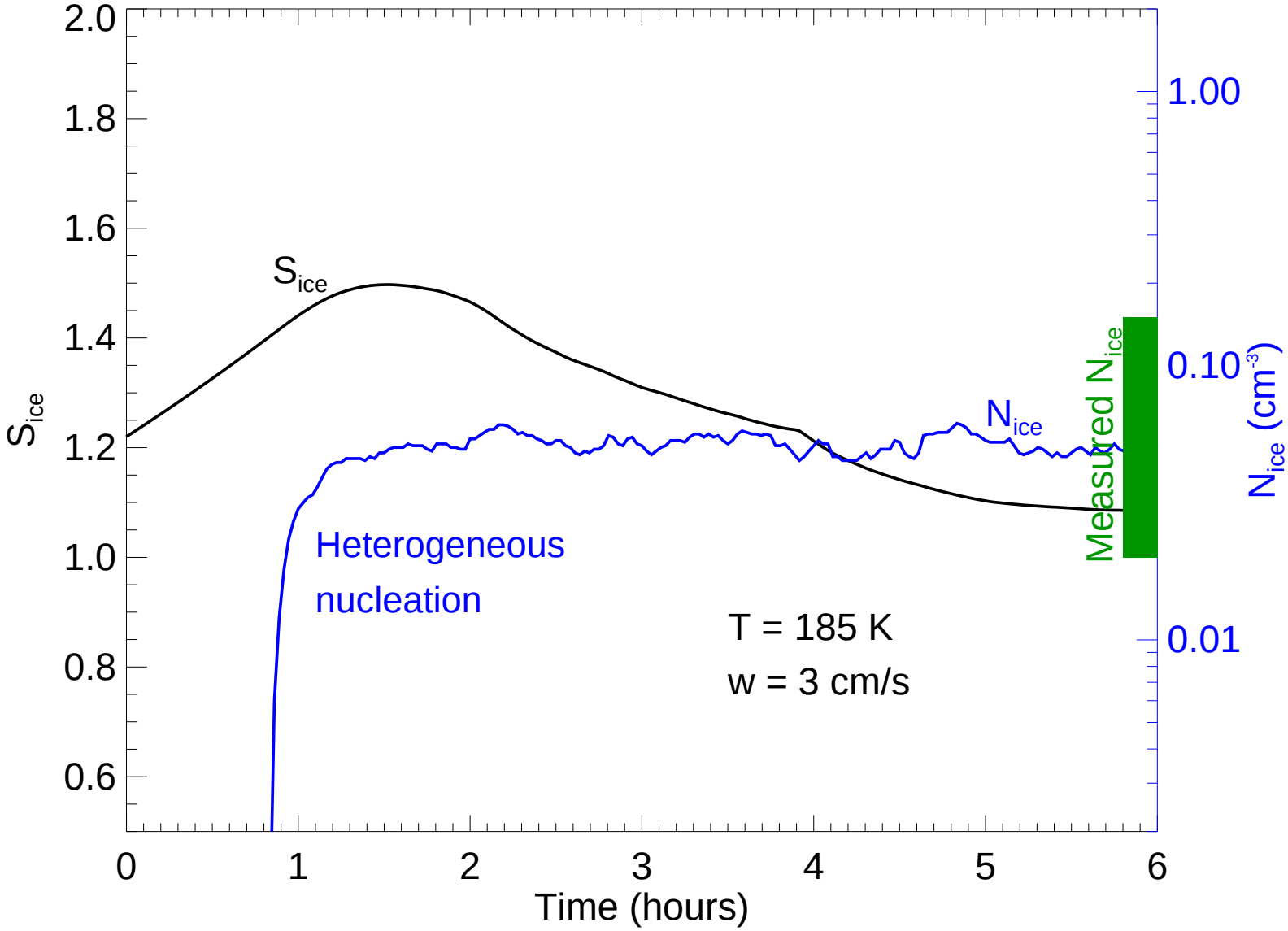
- Homogeneous freezing produces ice concentrations that exceed measured values.

Homogeneous freezing with gravity wave



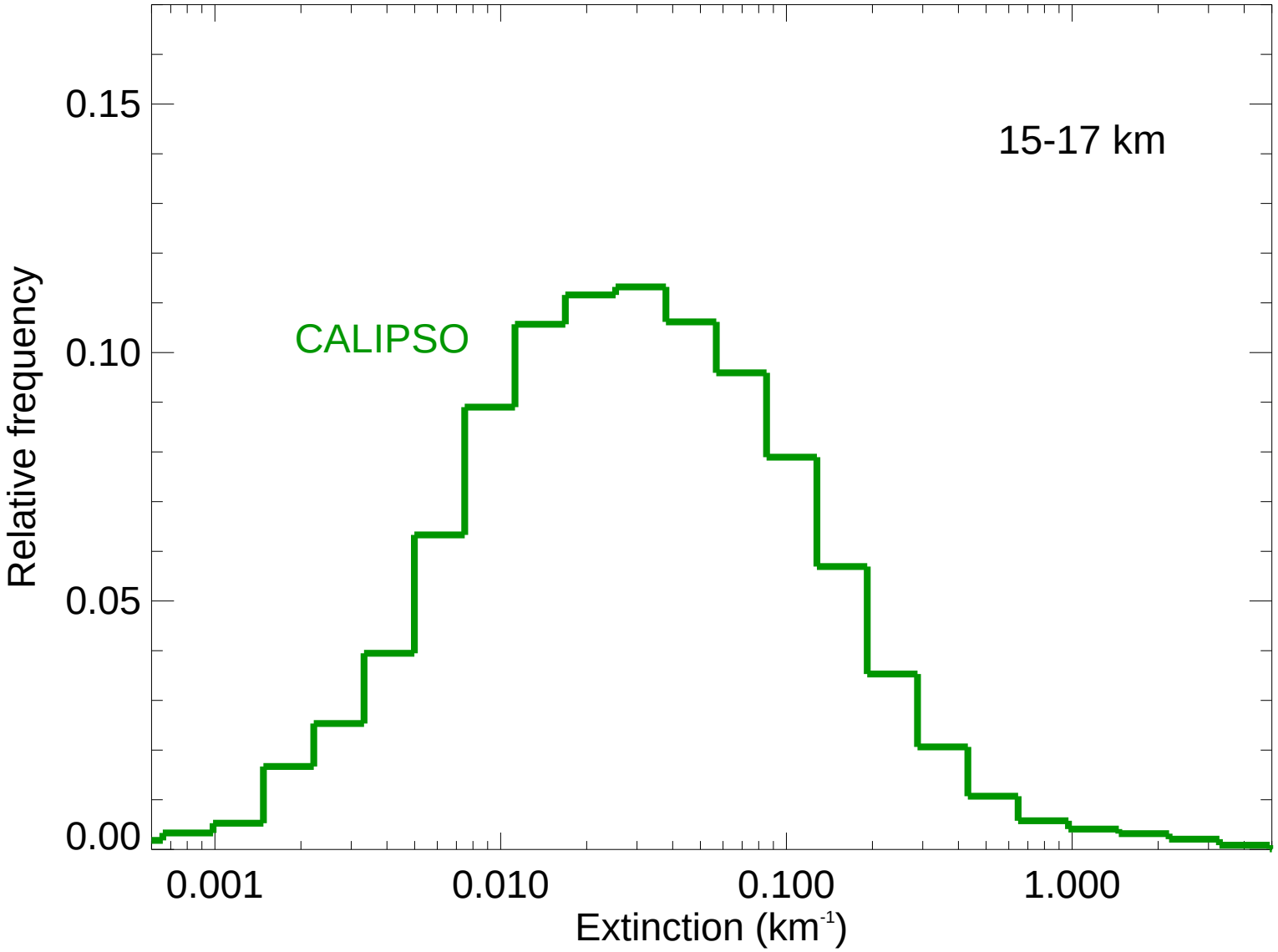
- Including gravity waves makes the situation worse.

Heterogeneous nucleation (slow cooling)

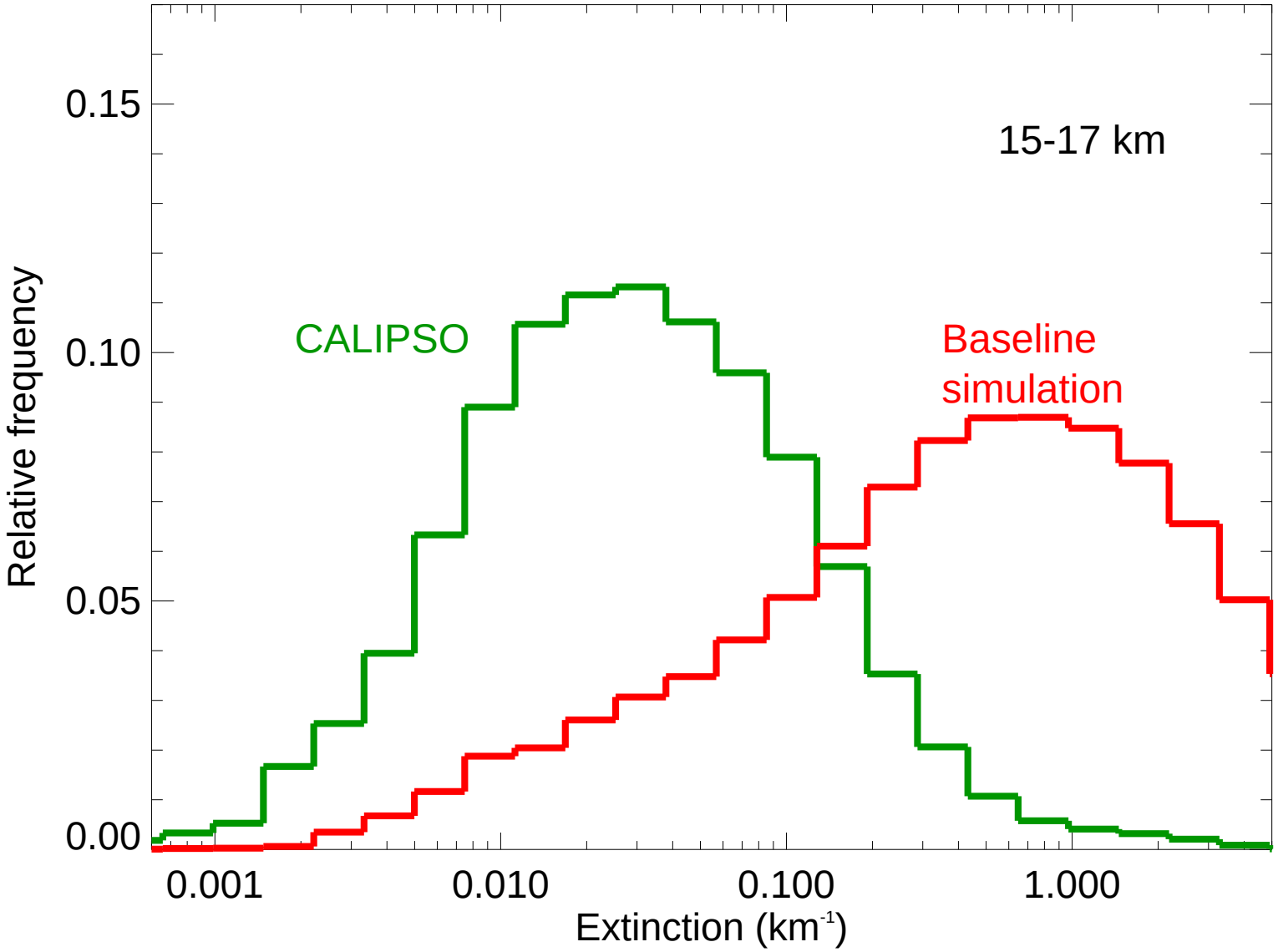


- Heterogeneous nucleation could explain the measured ice concentrations.

Extinction frequency distributions

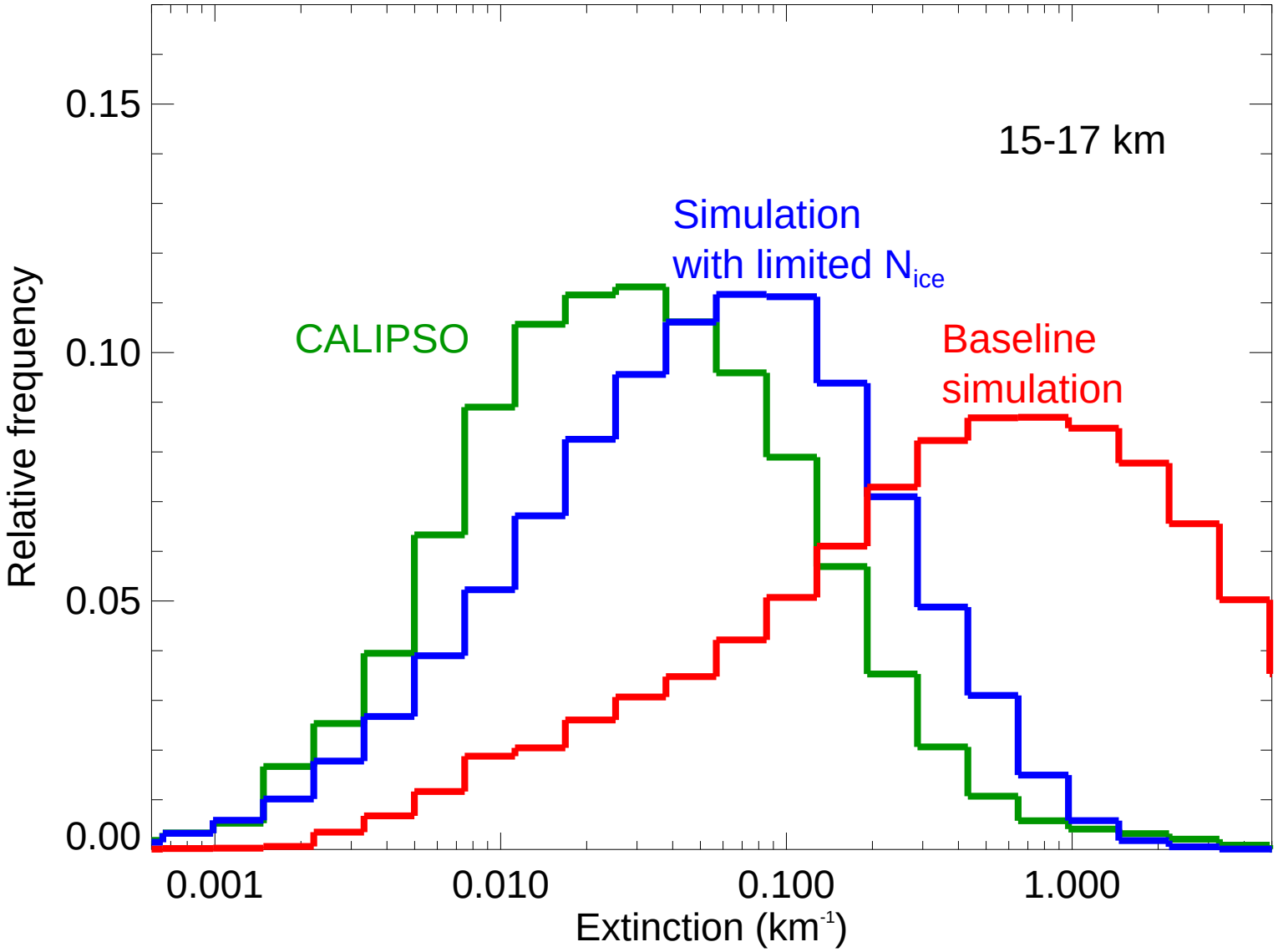


Extinction frequency distributions



- Simulations with homogeneous freezing (and waves) produce far larger extinctions than indicated by CALIPSO.

Extinction frequency distributions



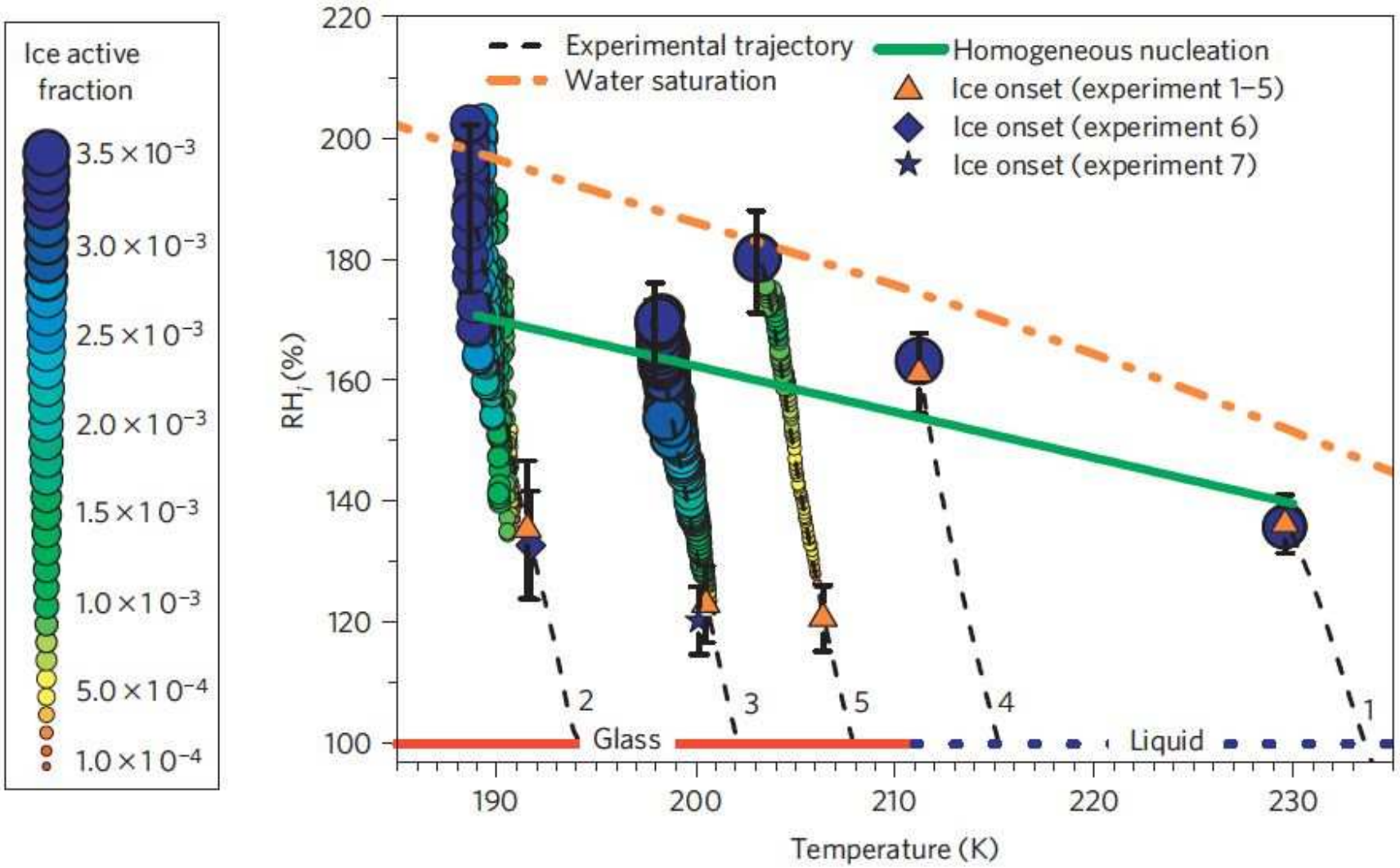
- Limiting ice concentration improves the agreement with observations.

To get lower ice concentrations and broader distributions...

- Generate $\simeq$50 L^{-1} ice crystals first
  - Ice nuclei (**ammonium sulfate**, oxalic acid, ...)
  - However, IN should be scavenged
- Differential ice growth
  - Cubic ice
  - Favorable defects/habits
- Only a small fraction of aerosols can freeze
  - Organic-containing aerosols transition to glassy state at low T, preventing nucleation

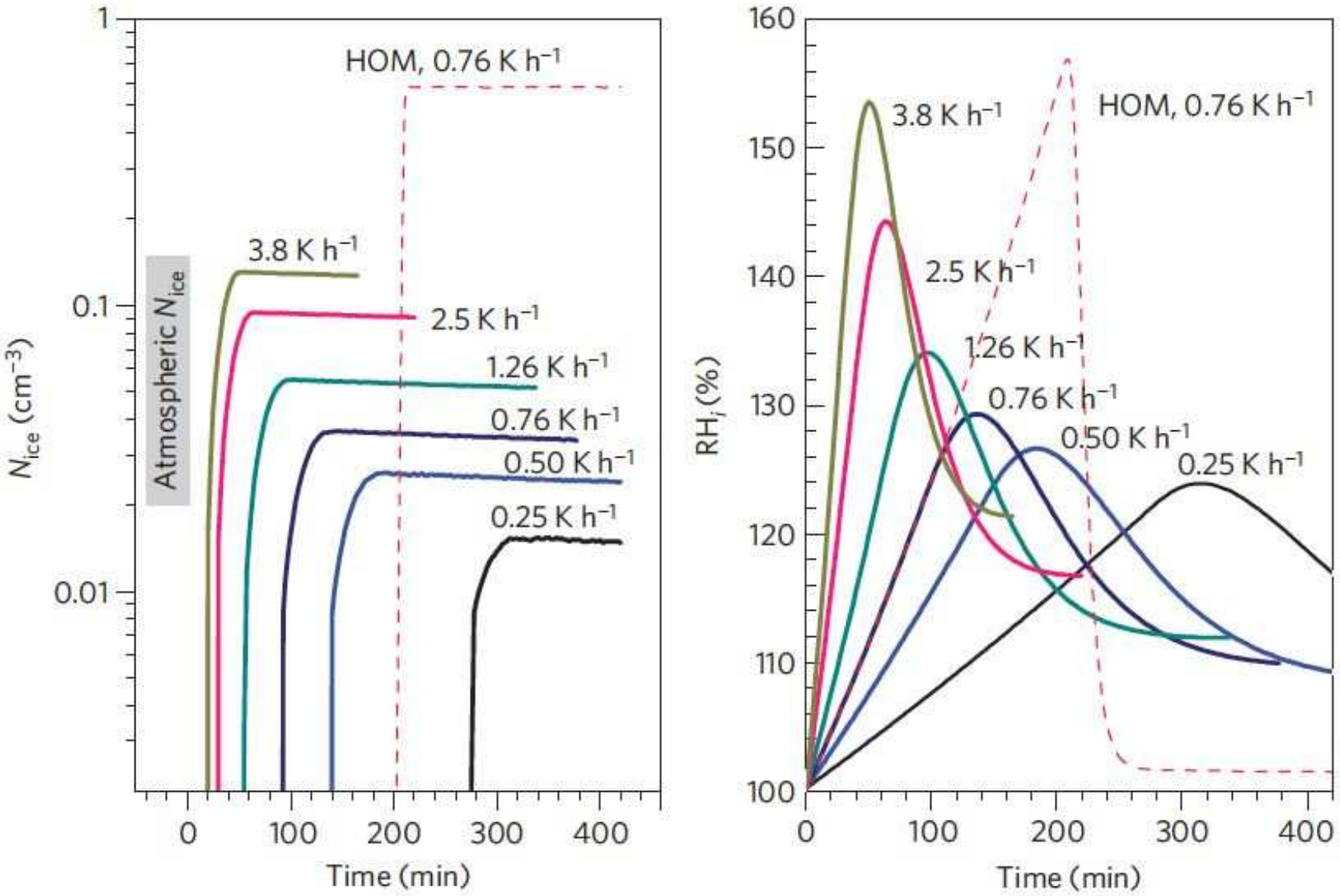
Glass formation in aqueous organic aerosols

- Indicated by two independent laboratory studies
  - Zobrist et al. [ACP, 2008]
  - Murray [ACP, 2008]
- Depends primarily solute molar mass ($M_w > 150$ g mol^{-1})
- High viscosity inhibits ice nucleation and growth
- Prevention of homogeneous freezing requires glass formation in vast majority of aerosols
  - N_{aer} ($\simeq$100 cm^{-3}) $\gg$ N_{ice} ($\simeq$0.01–5 cm^{-3})



- Heterogeneous nucleation on subset of glassy aerosols

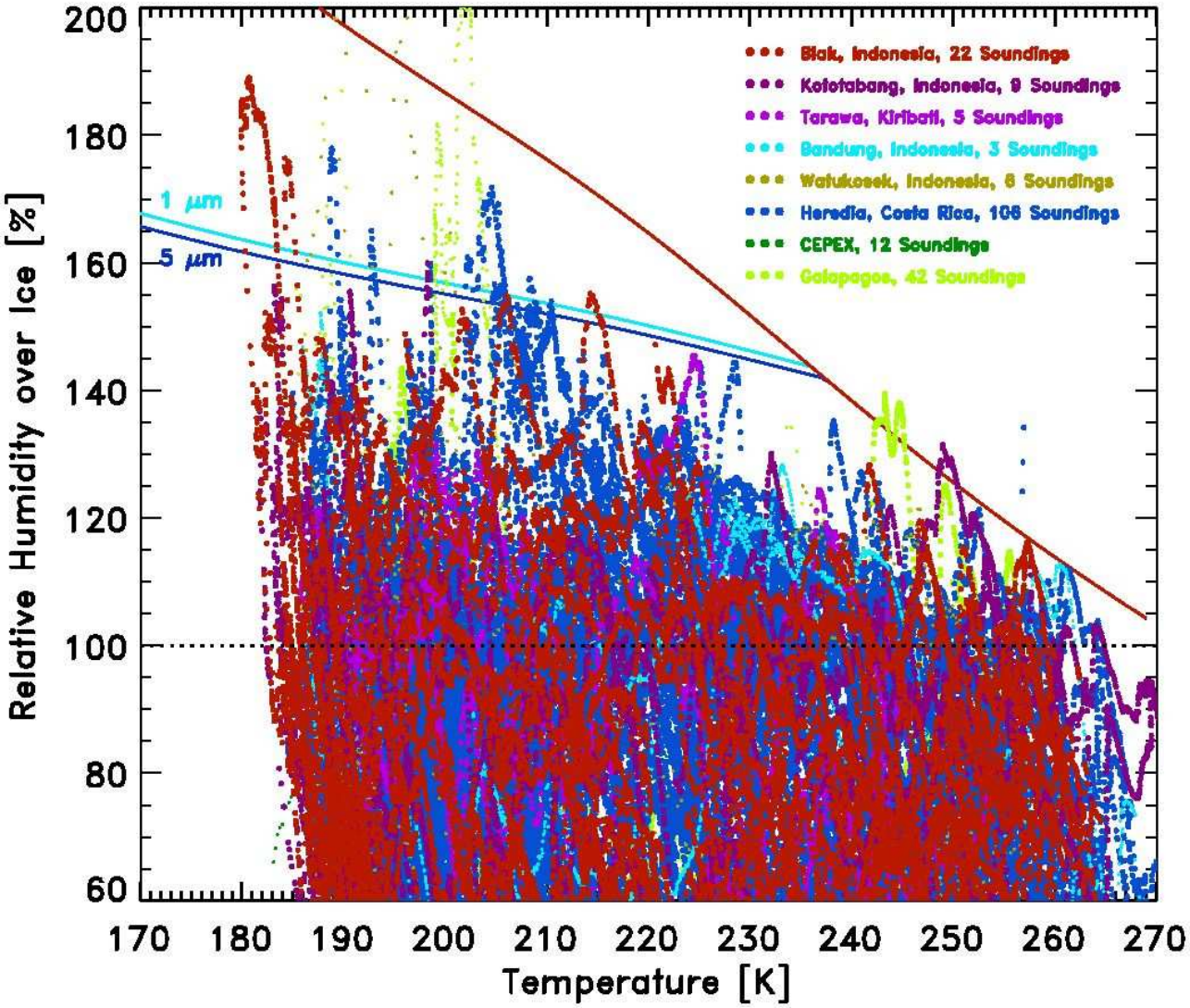
Murray et al. [2010]



- Heterogeneous nucleation glassy aerosols can provide low ice concentrations

Murray et al. [2010]

Supersaturation: Balloon-borne frostpoint soundings (H. Vömel)



- Both clear-sky and in-cloud supersaturation occur frequently in the TTL

What ATTREX can provide...

- CPL will provide statistics of TTL cirrus occurrence frequency and extinction with better sensitivity than CALIPSO
  - Requires level flight legs above tropopause over cold pools
- Extensive measurements of cold cloud microphysical properties and relative humidities
  - Requires porpoising through cloud layers at altitudes identified by CPL an Hawkeye
- Lagrangian flights indicating RHI threshold for nucleation, evolution of cloud properties and impact on water vapor
  - Requires Lagrangian flights in and out of cold pools at cloud altitude (below tropopasue)
- Case studies for process models